L3: POWER MANAGEMENT IN EMBEDDED SYSTEMS, MCU PIN ASSIGNMENTS

ESE516: IoT Edge Computing

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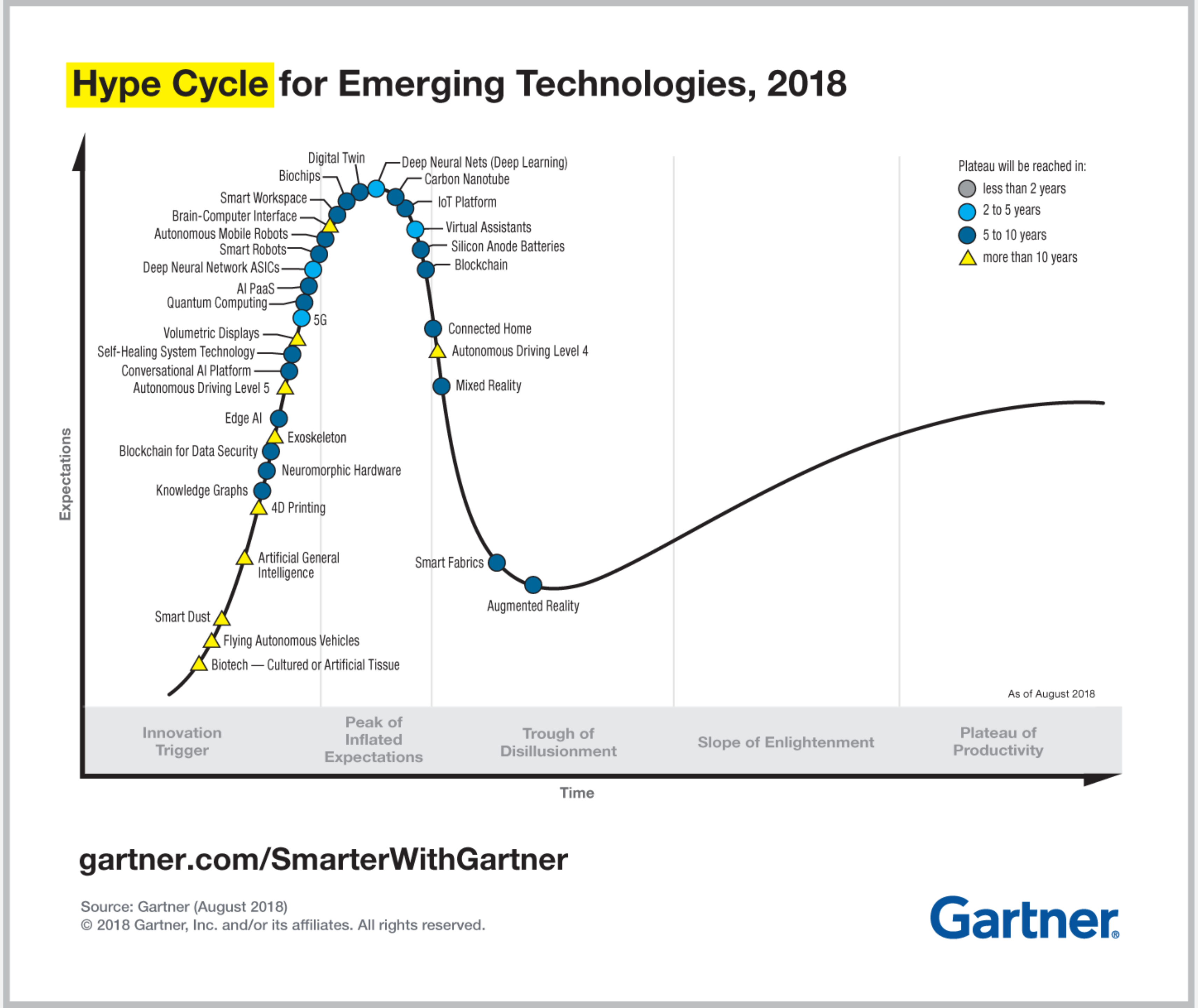
NINTENDO SWITCH JOYCON REVERSE ENGINEERING

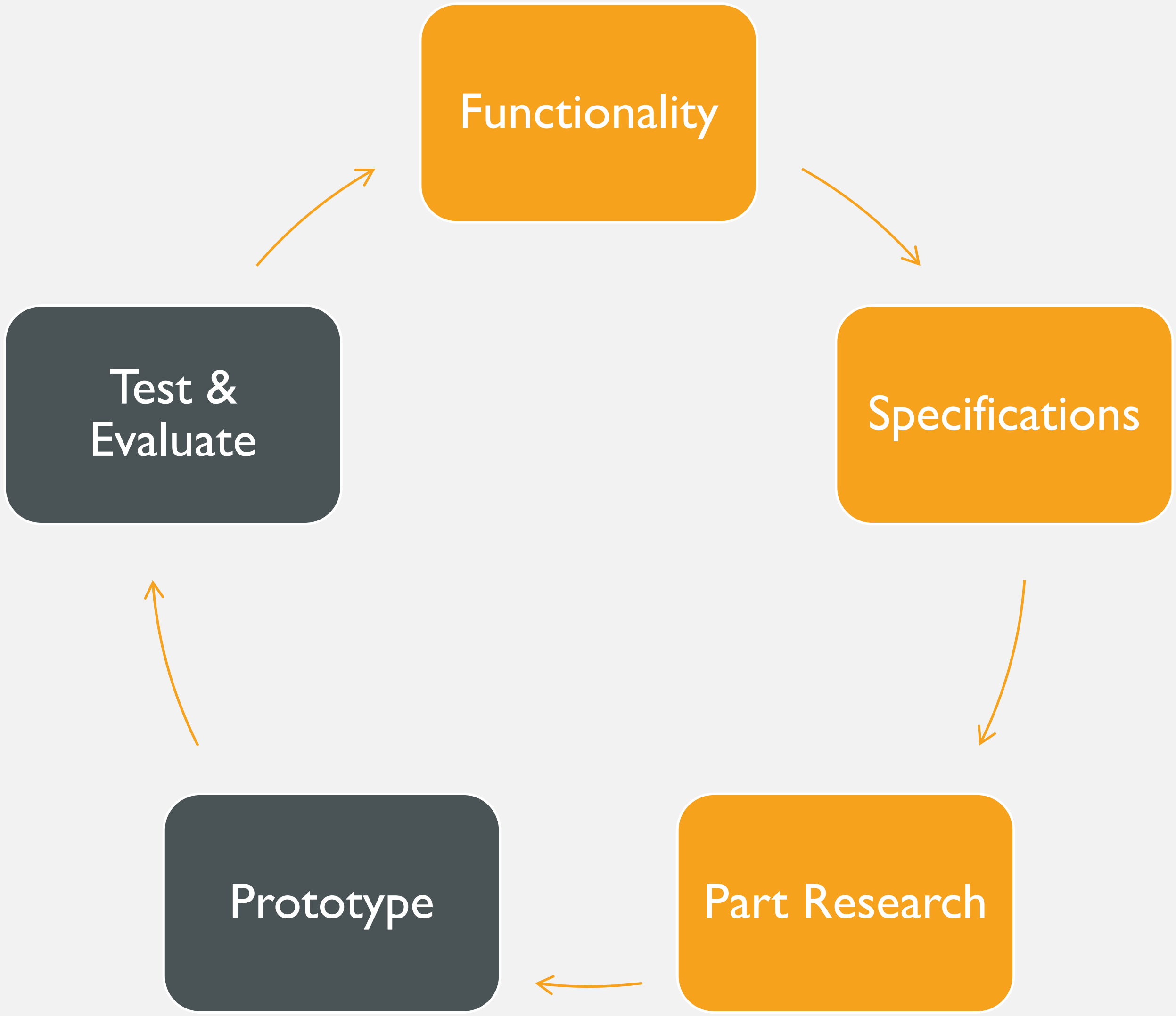
https://github.com/dekuNukem/Nintendo_Switch_Reverse_Engineering



https://blogs.gartner.com/smarterwithgartner/files/2018/08/PR_490866_5_Trends_in_the_Emerging_Tech_Hype_Cycle_2018_Hype_Cycle.png

REVIEW

PRODUCT DESIGN CYCLE*



*Though we'll be focusing on the electrical engineering, mechanical, industrial, and human factors design is critical to making a cohesive product.

CURRENT STATUS

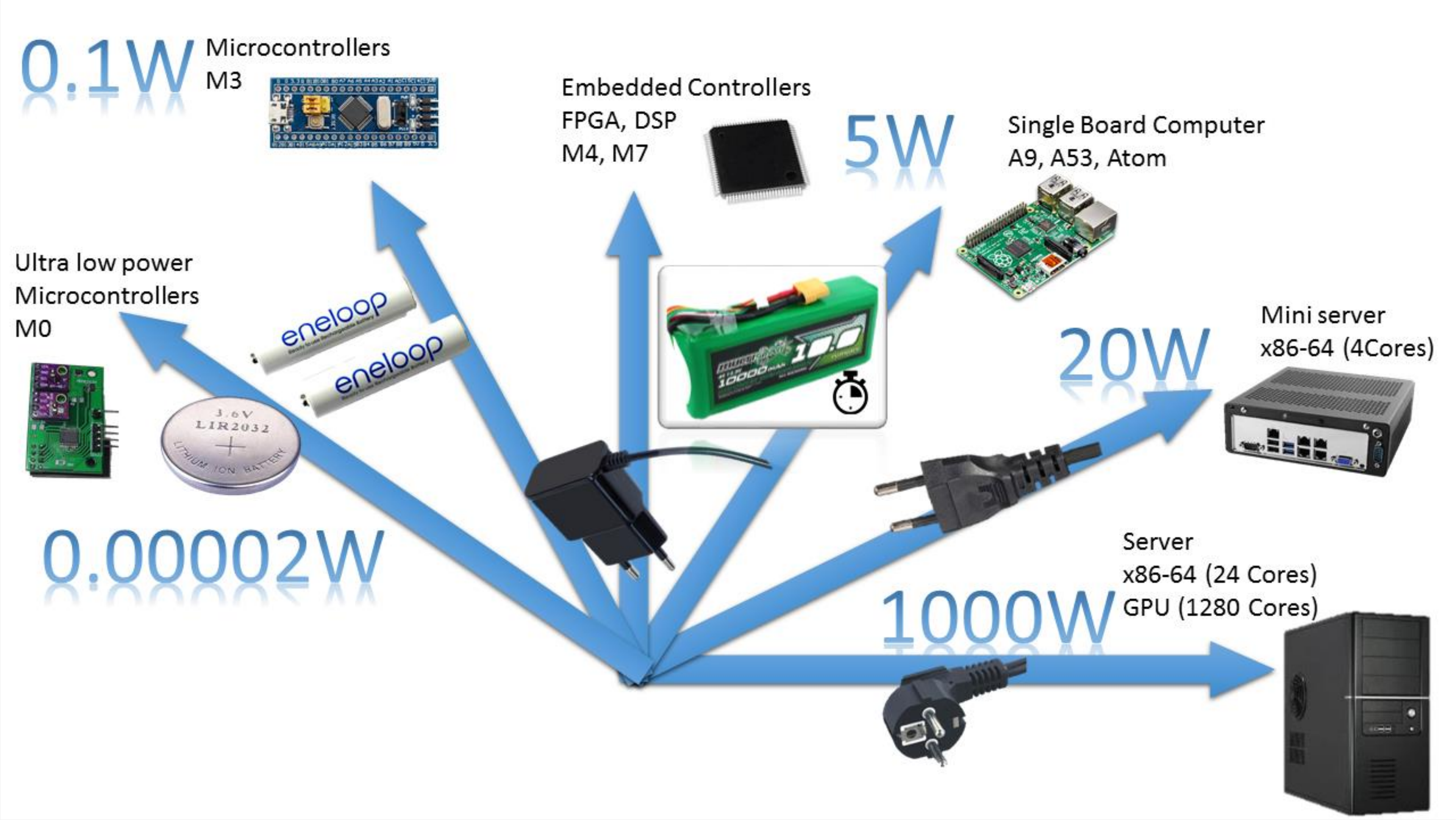
- We thought of ideas that benefited from cloud connectivity
- We chose the most vital components (sensors/actuators) for our idea
- We have a rough idea on the power they need (and the voltages they need!)

POWER PRIMER

FIRST STEP – POWER BUDGET

1. Not glamorous – But vital for any product
2. Allows us to get a rough estimate on power consumption and answers:
    1. What Voltages do we need?
    2. What current capacity do we needs?
    3. What characteristics must our power source have?
        1. Current discharge capacity
        2. Voltage
        3. Volume

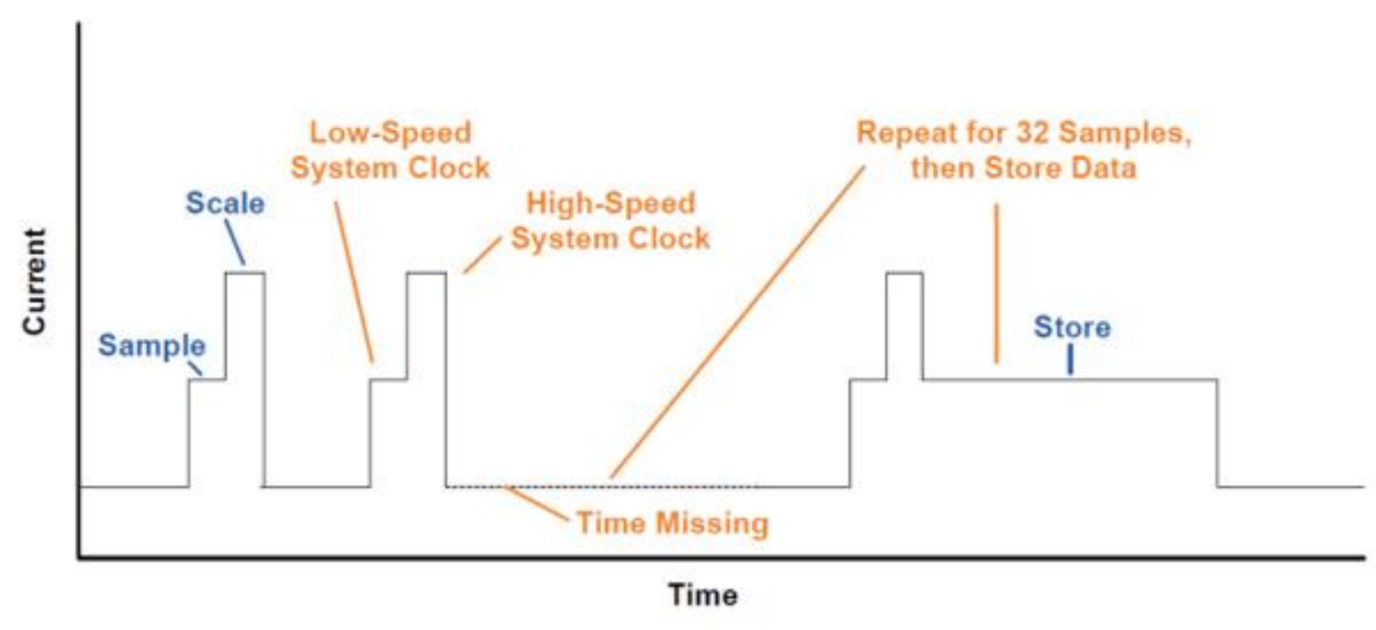
FIRST STEP – POWER BUDGET



FIRST STEP – POWER PROFILE

Mode	Mode Time for 32 Samples (ms)	Current (µA)		Charge (µA × ms)
		By Device	Mode Total	
Sleep MCU Sleep Sensor Off EEPROM Off	3200	0.8 0 0	0.8	2560.0
Initialize MCU Wake-up Sensor Off EEPROM Off	0.32	0.8 0 0	0.8000	0.26
Sample Sensor MCU Run Sensor On EEPROM Off	1.28	150 16.5 0	166.5	213.12
Scaling MCU Run Sensor Off EEPROM Off	0.32	1300 0 0	1300	416.00
Storing MCU Run Sensor Off EEPROM On	5	150 0 1000	1150	5750.00
TOTAL	3206.92	—	—	8939.38

Average Current (µA)	2.788



Recommended Read: https://www.digikey.com/en/articles/techzone/2012/feb/developing-energy-budgets-for-low-power-sensing-systems---part-ii-the-art-of-the-power-budget

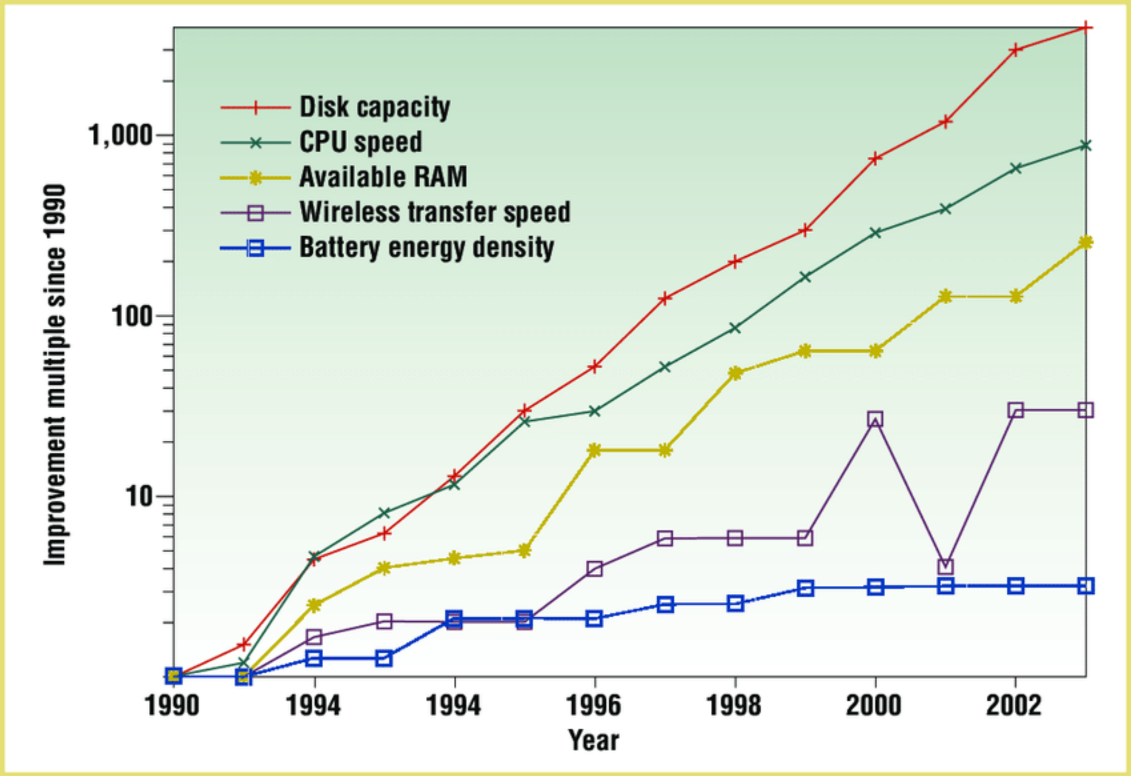
POWER SOURCE

SECOND STEP– POWER SOURCE

1. Once we know the power requirements of our system, we can proceed to find a power source for our solution

   - The type of power source depends on the product's specifications and type

   - Most IoT products are battery operated



PRIMARY BATTERIES VS SECONDARY BATTERIES

- Primary Batteries (Non-rechargeable)
- PROS
  - More affordable
  - Long shelf life
  - Readily available (easy for user to interact with, change batteries)
- CONS
  - Lower energy density
  - Lower current discharge capacity
  - High internal resistance

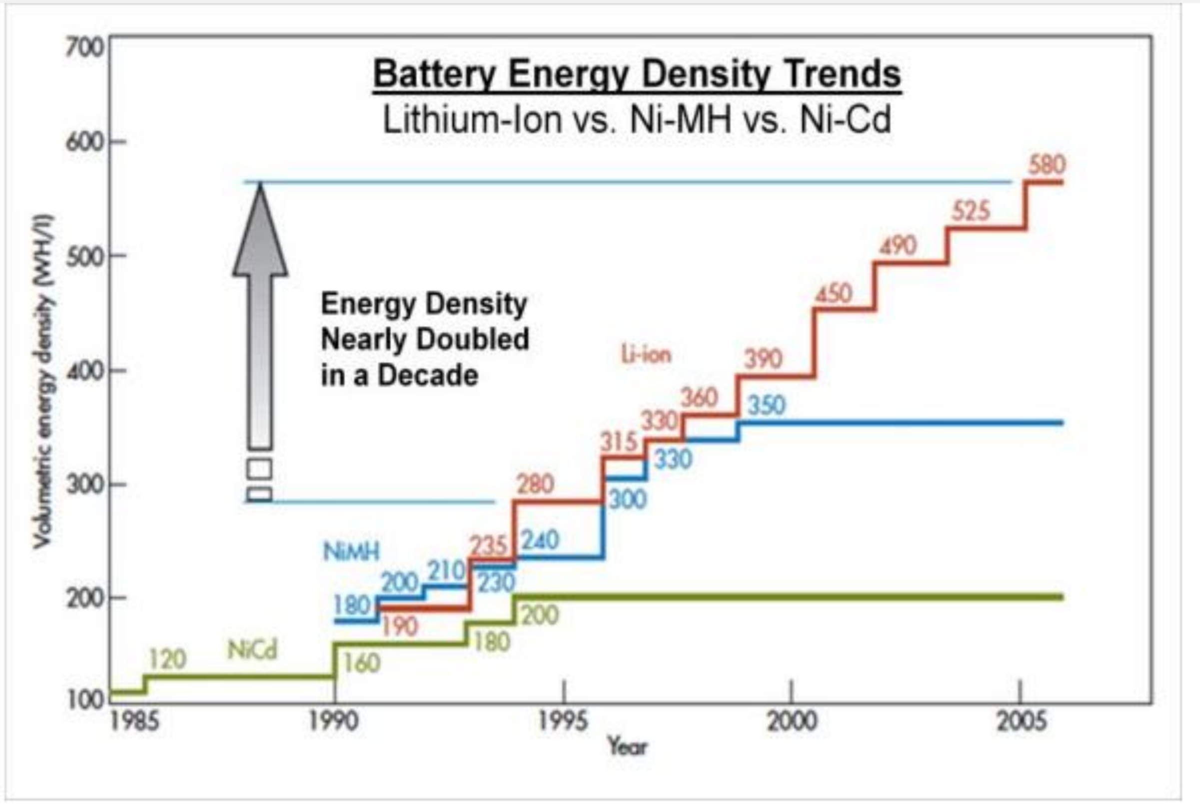
- Secondary Batteries (rechargeable)
- PROS
  - Rechargeable
  - More complex circuitry
  - Higher energy density
  - Great current discharge capacity
- CONS
  - Higher initial cost

PRIMARY BATTERIES VS SECONDARY BATTERIES

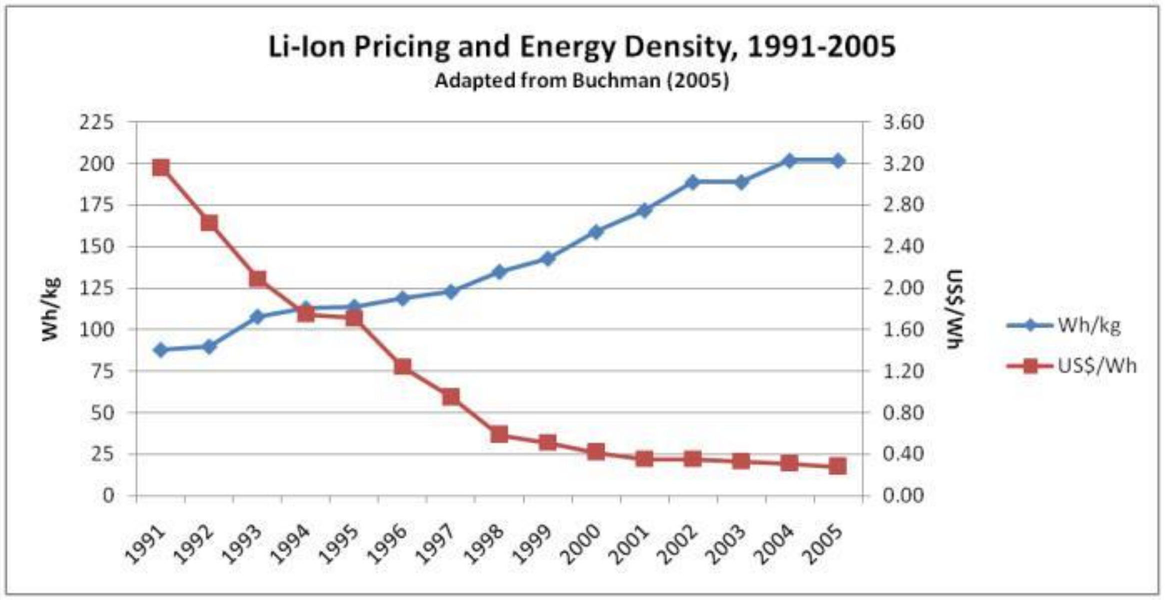
Xeno XL-060F
AA Size Primary
2400mAh
Lithium Thionyl Chloride
Maximum Current:
Continuous 60mA;
Pulse 120mA
Weight: 0.02lb (17g)
9Whr

LiFePO4 Rechargeable 14430 Cell:
AA SizeSecondary
400mAh
Maximum Current:
Continuos 0.8A;
Weight: 0.6 oz (17.0 grams)

REASON LI-ION IS SO USED



https://www.researchgate.net/figure/Battery-Energy-Density-Trends-Improvements-in-Lithium-Ion-battery-technology-has_fig6_268459609



https://www.greencarreports.com/news/1083392_cheaper-electric-car-batteries-slow-steady-wins-the-race

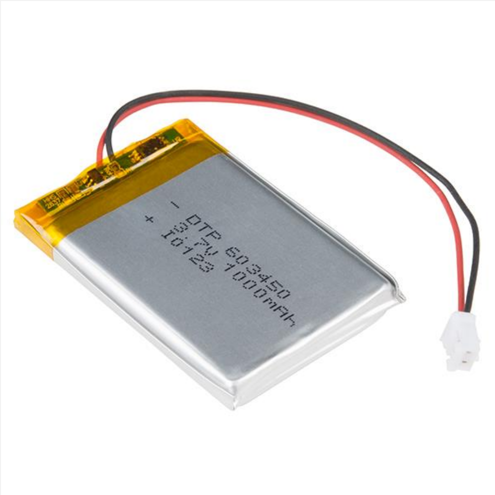
PRIMARY BATTERIES VS SECONDARY BATTERIES

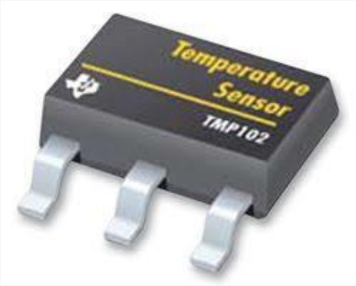
- Suggested Readings:
- https://www.iot-architect.de/iot-use-case-battery-powered-device
- https://www.rei.com/learn/expert-advice/batteries.html

POWER ARCHITECTURE

GETTING THE VOLTAGE TO WHERE WE NEED IT

- We have out input energy needs
- We have our components we want to power: Sensor/Actuators, MCU, ETC.
- The power architecture will help us get there!



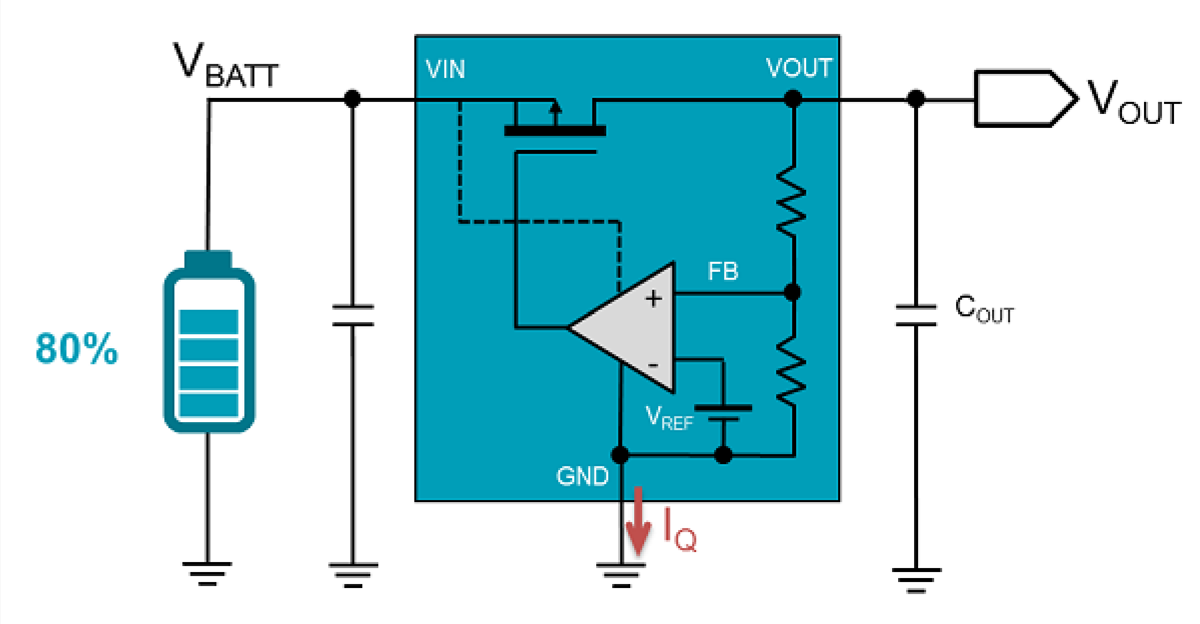


GETTING THE VOLTAGE TO WHERE WE NEED IT

- Assuming we have DC voltage from a source such as a battery, we have to either increase the voltage or decrease it

- These type of circuits are called DC Voltage Regulators

- Types of interest for this class
  - Linear Regulators
  - Switching Regulators

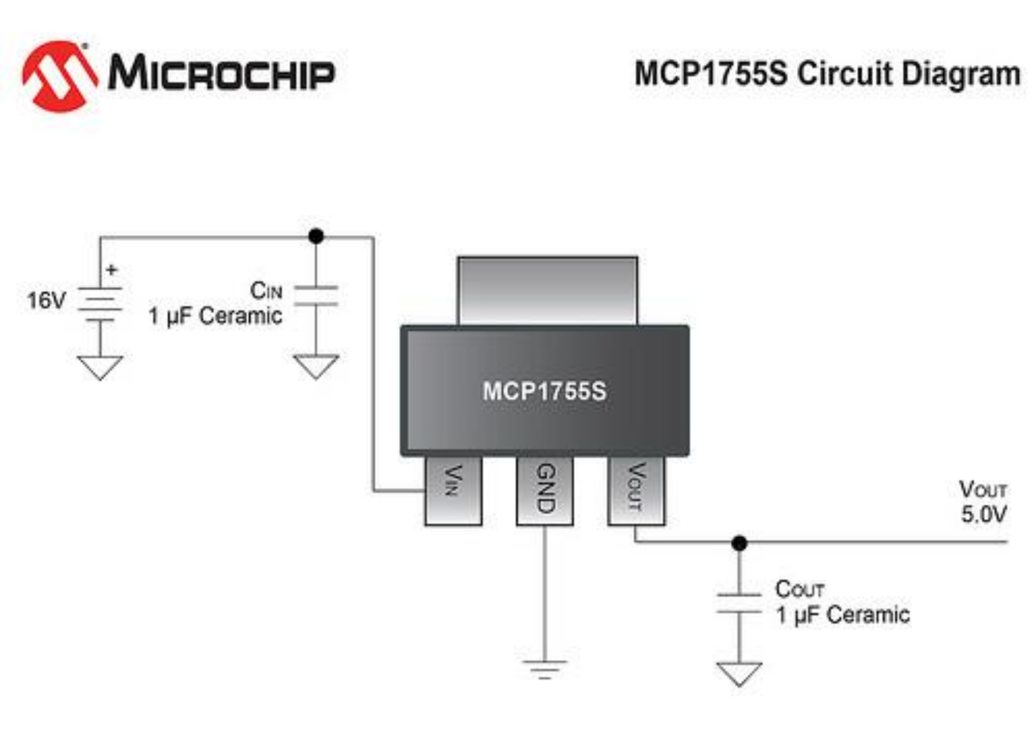


https://www.richtek.com/Products/Linear%20Regulator?sc_lang=en

REGULATORS

LDO Regulator

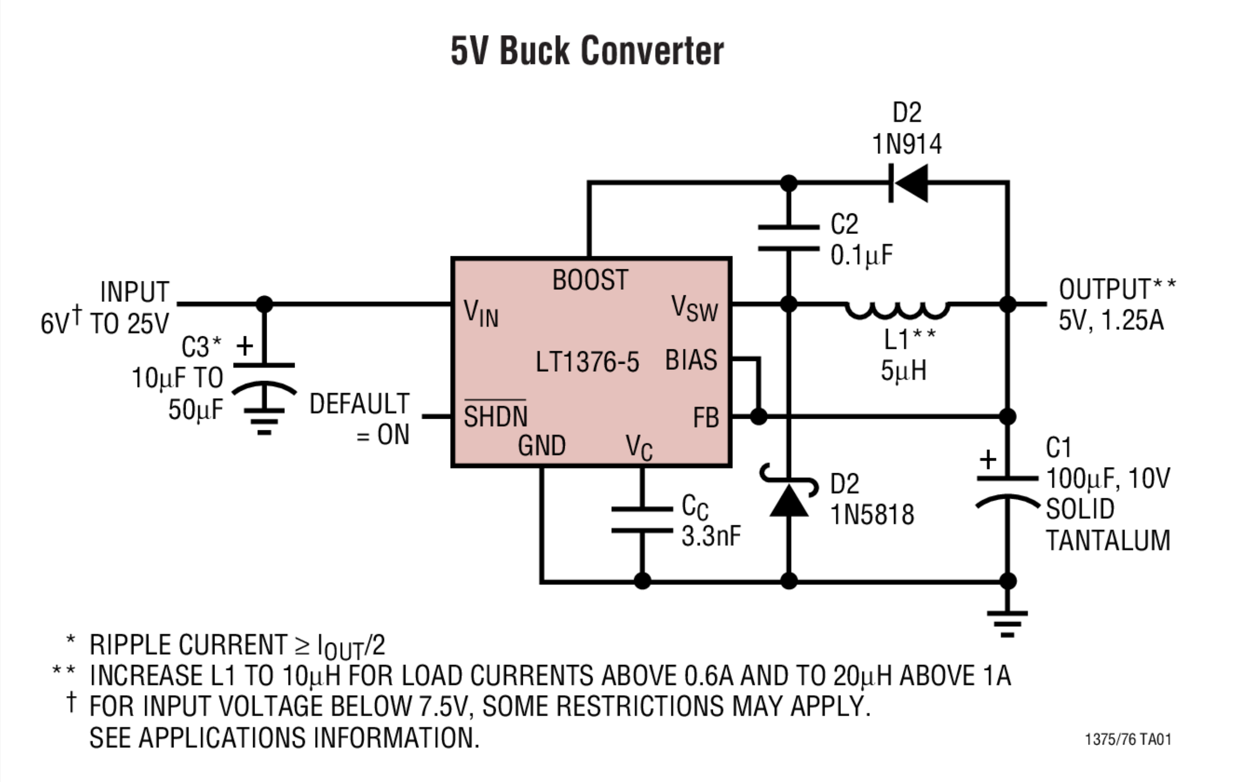
- Used to drop down voltage (Example: 5V to 3.3V)
- Very easy to implement
- Needs some headroom to work (The Dropout voltage)
- Very low noise on the output
- Energy waste if difference in input and output voltages is too big



REGULATORS

DC/DC Buck Regulator

- Used to drop down voltage (Example: 5V to 3.3V)
- Complex to implement – but we have online tools to help!
- Very good efficiency – good to use when the difference between input and output voltage is big
- EMI issues – layout must be very well done!



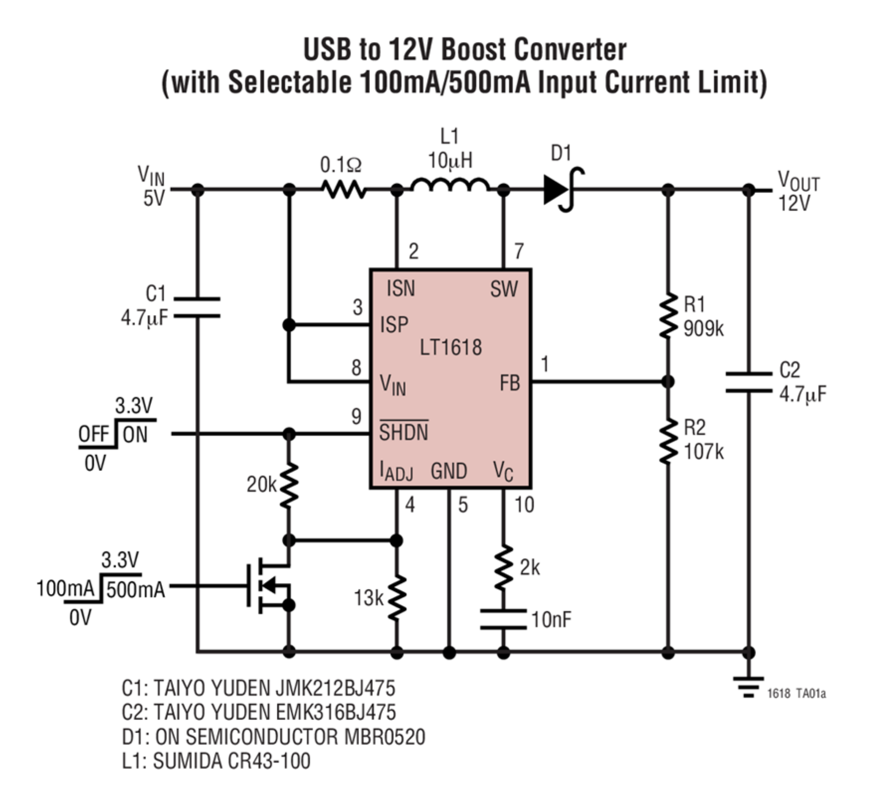
REGULATORS

DC/DC Boost Regulator

- Used to increase voltage (Example: 3.3V-4.2V to 12V)

Same issues as Buck

- Complex to implement – but we have online tools to help!
- Very good efficiency – good to use when the difference between input and output voltage is big
- EMI issues – layout must be very well done!



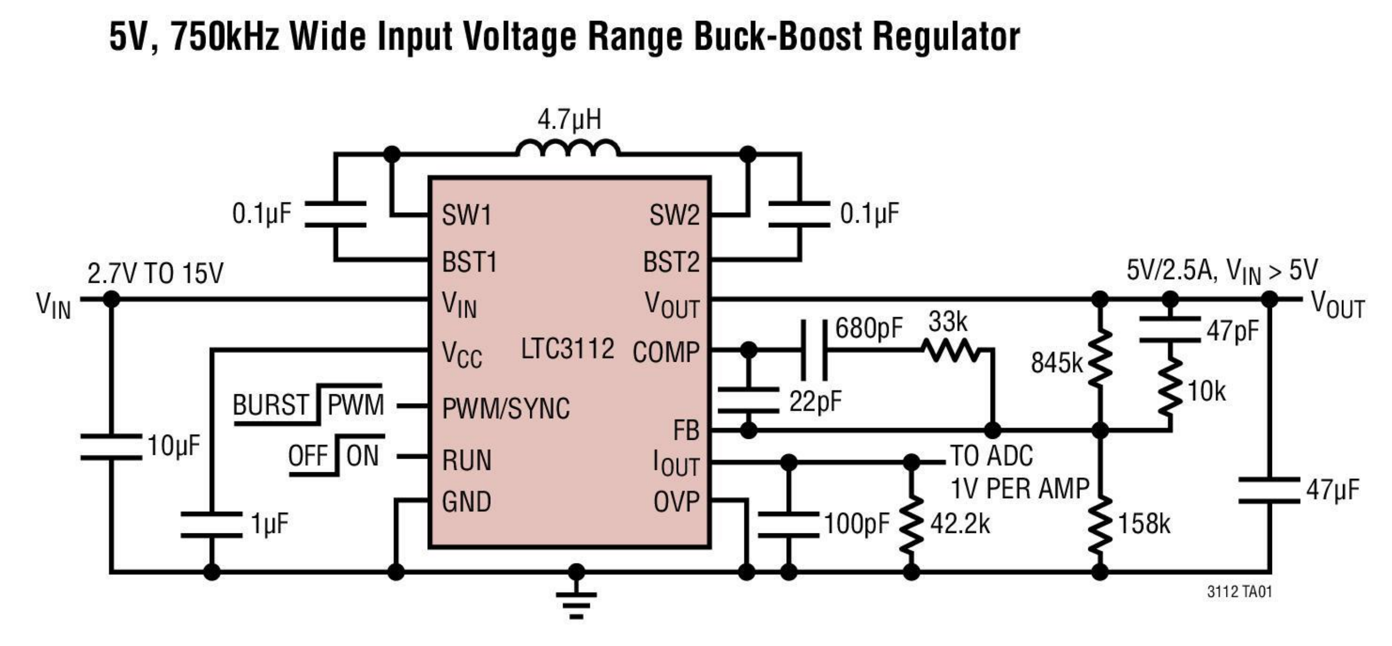
REGULATORS

DC/DC Buck/Boost Regulator

- Used to bring an input voltage that can be lower or higher than the output voltage (Example: 2.7V-15V to 5V)

Same issues as Buck and boost

- Complex to implement – but we have online tools to help!
- Very good efficiency – good to use when the difference between input and output voltage is big



- EMI issues – layout must be very well done!

SO…WHAT'S NEXT?

Now that you know the circuits you need - You

SO…WHAT'S NEXT?

Now that you know the circuits you need – How can you design these complex circuits?

- You can do it by hand, following the Datasheet and Recommended Circuits / App Notes

- Vendors provide you with tools online to design your system

- I recommend the following:
- https://webench.ti.com/power-designer/switching-regulator

LIVE DEMO -TI WEBENCH

POWER SUPPLIES

- Digital, analog, internal regulator pins
- Typical to use **ferrite beads in series** to remove noise from analog power
  - If noisy circuit – in line with all power for the MCU
- Internal MCU regulation to lower core voltage
- Lower voltage = lower power consumption
  - Worse signal to noise though!

6.2.1 Power Supplies

The Atmel® SAM D21 has several different power supply pins:

- VDDIO: Powers I/O lines, OSC8M and XOSC. Voltage is 1.62V to 3.63V.
- VDDIN: Powers I/O lines and the internal regulator. Voltage is 1.62V to 3.63V.
- VDDANA: Powers I/O lines and the ADC, AC, DAC, PTC, OSCULP32K, OSC32K, XOSC32K. Voltage is 1.62V to 3.63V.
- VDDCORE: Internal regulated voltage output. Powers the core, memories, peripherals, DFLL48M and FDPLL96M. Voltage is 1.2V.

The same voltage must be applied to both VDDIN, VDDIO and VDDANA. This common voltage is referred to as V_{DD} in the datasheet.

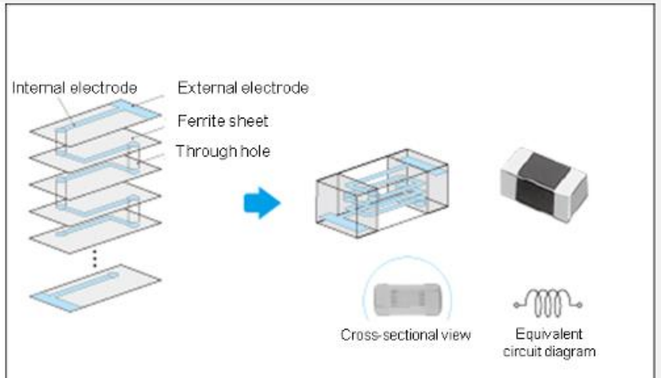
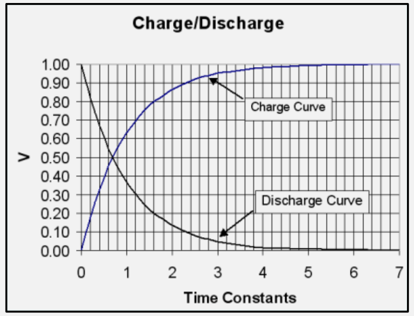
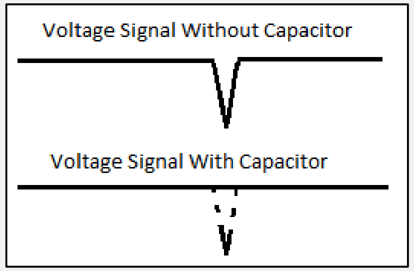


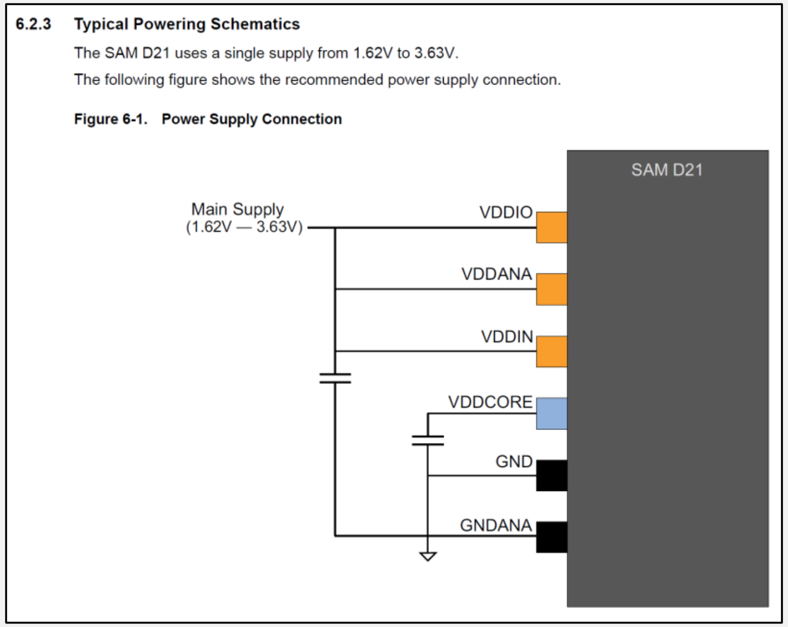
Fig. 2 Example of structure of BLM series of chip ferrite beads

DECOUPLING OR “BYPASS” CAPACITORS

- **What is it?**
  - Local Energy Reservoir
  - Voltage drops – holds the line up
  - Spike on the voltage line – extra energy is absorbed
  - Shunted to ground
  - Passes only DC component & smooths signal out
- **What happens without them?**
  - In digital circuits – unexpected behavior. IC resets / brownouts
  - In analog circuits, noisy signals.
  - If audio, you can hear hums and crackling







POWER SEQUENCE

1. Power manager controls how parts of the MCU are powered up
2. After power up, the device is held in reset until power is stabilized.
   1. Then, 1MHz clock from internal 8MHz RC oscillator divided by 8
3. I/O pins are tri-stated (high Z) after power up
4. After reset released, CPU fetches Program Counter (PC) and Stack Point (SP) from reset address – 0x00000000
   1. First executable address in internal flash.
   2. Clock & MCU configs can happen from here.

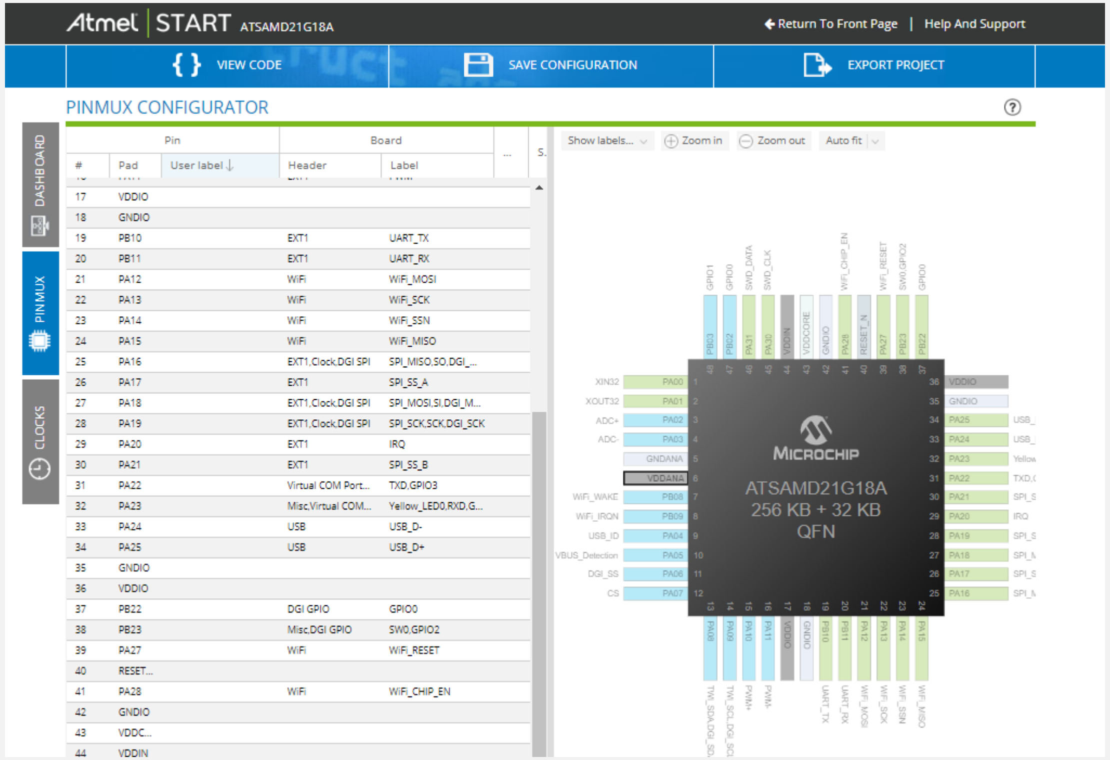
MCU PIN MAPPING

MCU PIN MAPPING AND MCU CLOCK

- Atmel offers Atmel Start, a web-based toold to help us set our MCU
- https://start.atmel.com/#dashboard/pinmux

- However, the code base is not mature enough to trust it for this class – but the pin mapping aspect can be good for our device.

- One day it might be, and ESE516 would make the jump from ASFV3 to ASFV4



MCU PIN MAPPING AND MCU CLOCK

- Recommendation for future: Use Atmel Start to check the pin configuration for your project:
- Which Pins should I use?
- Check SAMW25 and samd21g Datasheet

Table 3-1. Pin Description

Pin #	Pin Description	I/O Type	Function (default)	Programmable Pullup/-down Resistor
1	GND	N/A	Common Ground	
2	UART_TxD	WINC1500 Output	Currently used only for Atmel de-bug. Not for customer use. Leave unconnected.	Yes – Pullup
3	UART_RxD	WINC1500 Input	Currently used only for Atmel de-bug. Not for customer use. Leave unconnected.	Yes – Pullup
4	Wi-Fi Chip_En	WINC1500 Input	Currently used only for Atmel de-bug. Not for customer use. Leave unconnected.	No
5	Wi-Fi GPIO_1/RTC	WINC1500 I/O	ATWINC1500 General purpose I/O. Can also be used to input a 32.768KHz Real Time Clock for ac-curate timing of Wi-Fi sleep intervals	Yes – Pullup
6	NC	-	No connect	
7	VBAT	Power	Supply for Wi-Fi RF Power Amplifier and Internal 1.3V Switching Regula-tor	
8	PA16	See SAM D21G datasheet	See SAM D21G datasheet	Yes
9	PA17	See SAM D21G datasheet	See SAM D21G datasheet	Yes
10	GND	Power	Ground	
11	PA18	See SAM D21G datasheet	See SAM D21G datasheet	Yes
12	PA19	See SAM D21G datasheet	See SAM D21G datasheet	Yes
13	PA20	See SAM D21G datasheet	See SAM D21G datasheet	Yes
14	PA21	See SAM D21G datasheet	See SAM D21G datasheet	Yes

LIVE DEMO –MCU PIN MAPPING WITH ATMEL START

APPLICATION NOTES

APP NOTES

- Electronics are complex – don't try to reinvent the wheel
- App notes are manufacturers' "Cheat Sheets" for you
- Everything from programming to hardware connections.
- http://www.microchip.com/wwwproducts/en/ATSAMD21G18

SMART ARM-based Microcontrollers

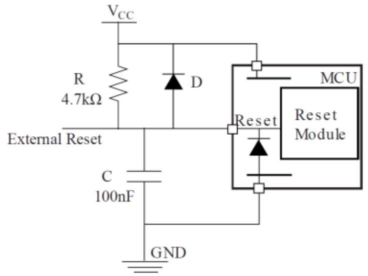
AT07347: Executing Code from RAM

APPLICATION NOTE

Preface

Executing code from RAM can be useful in cases where low power requirements demand this and in cases where low latency or fast execution is necessary. This application note explains how this can be done. There is an associated project for the SAM D20 that can be used as an example.

Figure 3-1. Recommended Reset Pin Connection

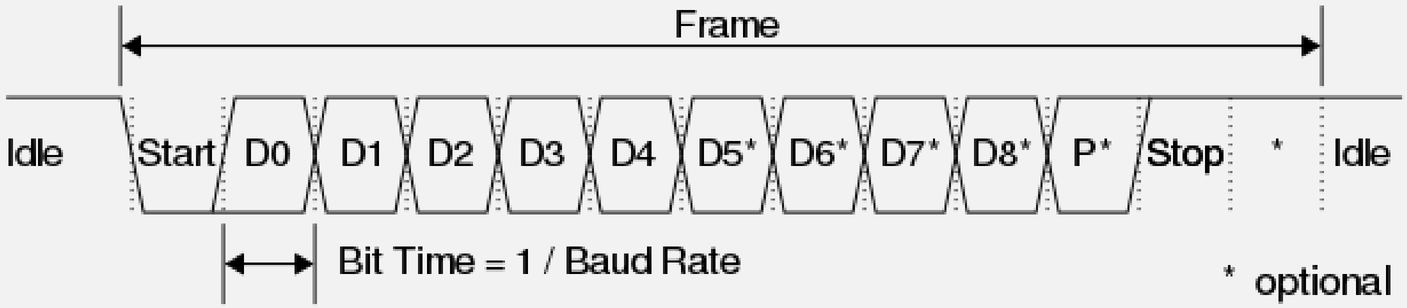


Note: The values of resistor R and capacitor C are typical values used for the RESET pin. For specific design requirements of an application, these values must be changed accordingly.

PROTOCOLS

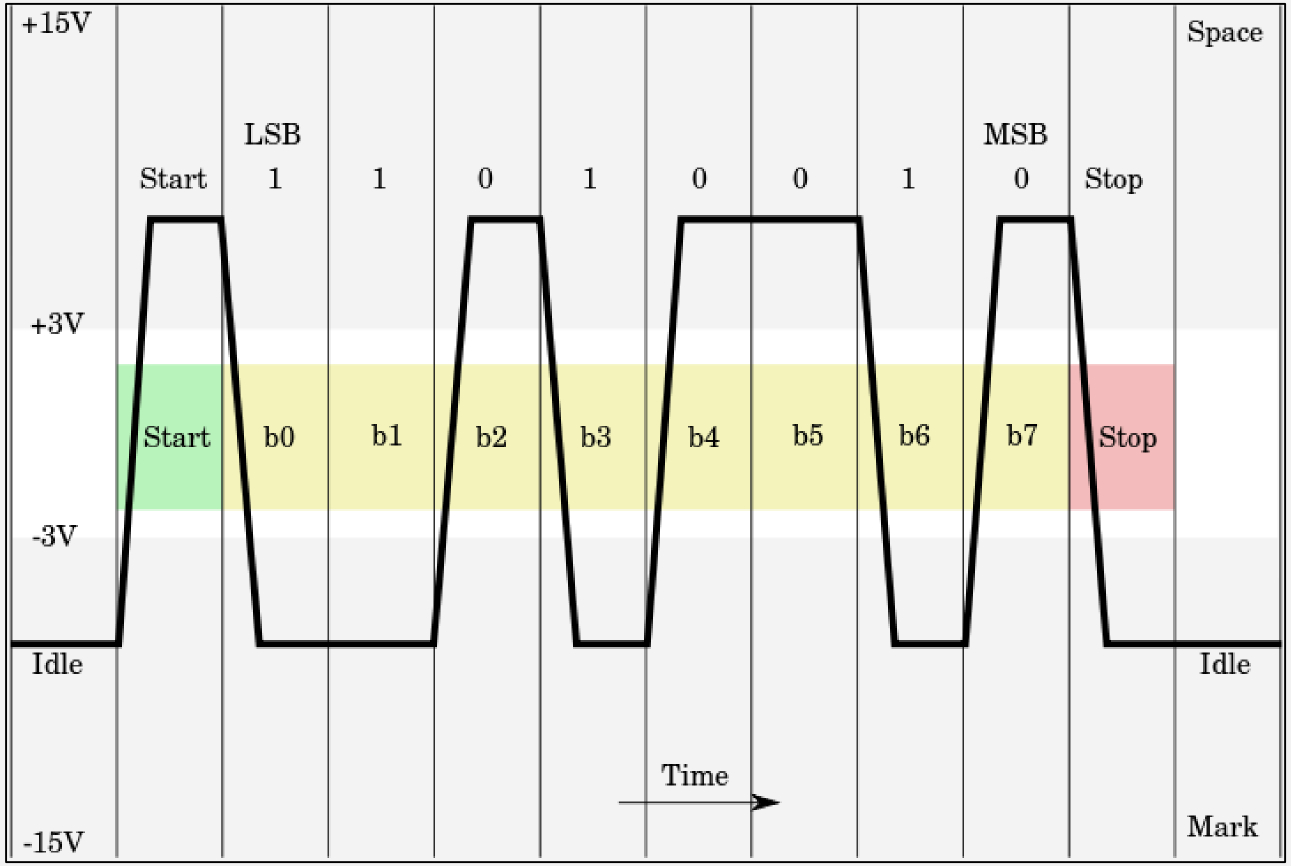
USART

- Universal Synchronous / Asynchronous Receiver Transmitter
- Simple way to create a user interface by transmitting ASCII characters
- Synchronous clocks out every bit
- Asynchronous uses start and stop bits



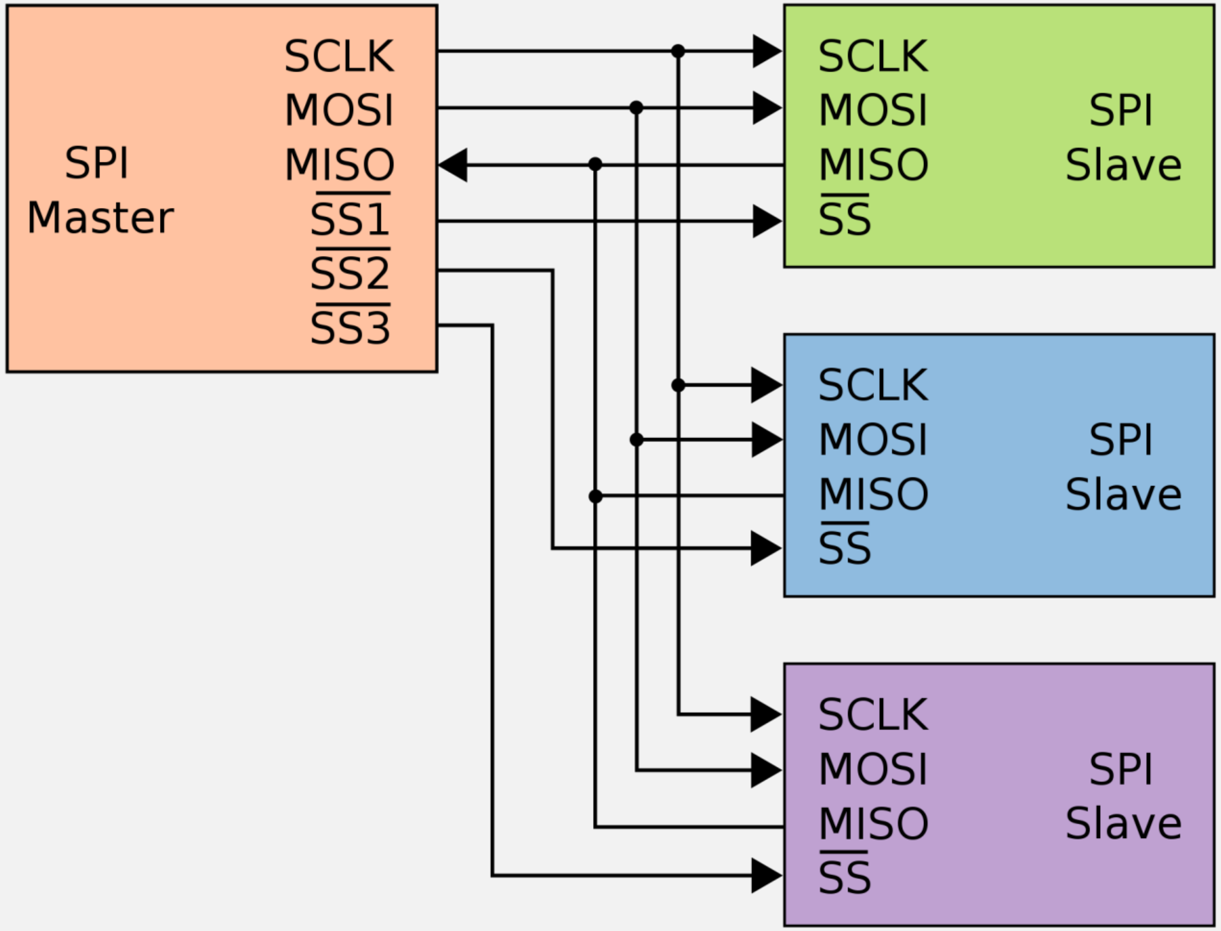
USART

- RS-232 and other communication standards specify voltage levels
- UART data can be sent with RS-232 voltage levels, which have a negative to positive swing for better noise immunity



(Q)SPI

- SPI = Serial Peripheral Interface
- "Quad" SPI is used when 4 channels are desired for increased throughput
- Frequently used for flash chip comms
- Supports one "master" and multiple slaves
  - A separate GPIO is necessary for each additional slave device.



I2C

- I2C = Inter-integrated Circuit
- Open-drain output
  - Requires resistors to pull up the lines!
  - Strength of the resistors depends on the number of devices on the bus and the length of the lines
  - Rise time of signal determines what will work
- Many devices can live on the same two lines